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RECOMMENDED PRACTICES FOR PRODUCTION OF SPHEROIDAL GRAPHITE IRON

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RECOMMENDED PRACTICES FOR PRODUCTION OF SPHEROIDAL GRAPHITE IRON

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Indian Standard

RECOMMENDED PRACTICES FOR PRODUCTION OF SPHEROIDAL GRAPHITE IRON

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 27 October 1980, after the draft finalized by the Foundry Sectional Committee had been approved by the Structural and Metals Division Council.

0.2 Spheroidal graphite iron (S. G. iron), also known as nodular and ductile iron, is finding increasing applications in the country as a substitute for non-ferrous metals and alloys as well as steel and malleable iron castings due to its superior properties in some respects. The production of S. G. iron in the country is steadily increasing but the rate of expansion in production would depend upon the ability of the industry to produce reliable products.

0.3 It was, therefore, felt that a standard describing the recommended practices to be used for production of S. G. iron castings would be of help to those foundries which are engaged in the production of S. G. iron as well as those which are contemplating to enter this field.

0.4 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This recommended practice describes the techniques used in the production of S. G. iron and covers topics, such as composition of base iron, charge materials, melting units, treatment alloys to be used, desulphurization techniques, magnesium treatment for spheroidization and inoculation techniques, gating practice and heat treatment of castings.

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*Rules for rounding off numerical values (*revised*).

1.2 This recommended practice does not cover the production of high alloy S. G. iron like austenitic S. G. iron.

2. GENERAL PROCEDURE INVOLVED IN PRODUCTION OF S. G. IRON

2.1 Production of S. G. iron involves firstly melting of base iron of right chemical composition and of right physical condition followed by treatment with either pure magnesium or an alloy containing magnesium with or without cerium, so as to leave a residual magnesium content of 0·03 to 0·05 percent in the treated iron. Magnesium is essentially a desulphuriser and its addition to the base iron first reduces the sulphur content to a very low level and then results in the formation of graphite in a spheroidal form instead of the flake form present in the normal grey iron. The magnesium treatment is invariably followed by the late addition of ferro-silicon as inoculation treatment in order to ensure good ductility in the S. G. iron produced. Simultaneous addition of spheroidizing and inoculating agents is also sometimes practised.

2.2 The aspects which need careful consideration in the production of sound S. G. iron castings are:

a) chemical composition of the base iron,

b) physical condition of the base iron,

c) charge materials,

d) melting units,

e) desulphurization of the melt,

f) treatment-alloys,

g) spheroidization techniques,

h) inoculation,

j) gating and risering practice, and

k) heat treatment of castings.

3. CHEMICAL COMPOSITION OF THE BASE IRON

3.1 The right chemical composition is the desired final composition of the castings, less alloys added during treatment and inoculation plus carbon loss during magnesium treatment. Certain elements have adverse effects on the formation of spheroidal graphite and some other elements affect either the heat treatment cycle or the mechanical properties of the treated iron or the economics of production. Elements of interest, their influence and desired range for base iron are discussed below.

3.2 Total Carbon — The total carbon in the base iron suitable for treatment is an important factor and is critical for treatment with cerium which requires hypereutectic iron with carbon equivalent of above 4·3 percent. For treatment with magnesium, the total carbon is not so critical and can be hypoeutectic, but it is preferable to have the carbon equivalent of the iron just below or as near as 4·3 percent. There is also a slight loss of carbon during treatment. Considering the above, a base iron containing 3 to 4 percent total carbon would be quite suitable for treatment with magnesium.

3.3 Manganese — Manganese is a carbide stabilizer and contributes to pearlite formation. The S. G. cast iron is a virtually sulphur free material and, therefore, the effect of the manganese present in the iron in stabilizing pearlite is much greater than in any other type of iron. The general effect of raising the manganese content is to raise hardness and lower impact strength. The manganese content, therefore, should be limited especially for the production of ferritic grades, for which it is desirable to keep the upper limit around 0·5 percent in heat treated grades. In as cast ferritic grades, the manganese content should be much lower at 0·2 to 0·3 percent.

3.4 Phosphorus — Phosphorus has a pronounced effect in decreasing the impact strength as well as lowering the elongation value. To gain the maximum resistance to impact as for grade S. G. 370/17 of IS : 1865-1974*, phosphorus must be kept as low as possible, preferably below 0·05 percent. The upper limit of phosphorus for the other three grades, which does not call for high impact strength can be somewhat higher, but should not normally exceed 0·08 percent to avoid any measurable reduction in elongation values and impact resistance. In special applications, such as for piston rings and railroad brakeshoes, phosphorus is intentially kept high around 0·30 to 0·60 percent to obtain high wear resistance.

3.5 Sulphur — Cerium and magnesium which are used for production of S. G. cast iron are strong desulphurizers and the chemistry of the formation of spheroidal graphite involves reduction of sulphur content of the metal to a very low level and leaving a certain residual content of these elements which promote the formation of spheroidal graphite. In view of this, sulphur in the base iron should be kept as low as possible so as to reduce the cost of treatment as well as to prevent appreciable fall in the temperature of the metal. A maximum of 0·035 percent sulphur is considered a satisfactory level for economic treatment. Although it is possible to treat irons containing higher percentages of this element, it is preferable to desulphurize the melt if it contains more than 0·035 percent sulphur.

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*Specification for iron castings with spheroidal or nodular graphite (*second revision*).

3.6 Silicon — The ultimate silicon content of the treated iron is required to be kept within 2·2 to 2·5 percent and should not exceed 2·75 percent particularly for impact resisting grades. Allowing for the silicon from the treatment alloy and the subsequent inoculation, the base metal should contain about 1·5 percent silicon, when silicon magnesium alloy is used and 2 percent when nickel magnesium alloy is used.

3.7 Nickel — Nickel acts as a graphitizer and decomposes carbide in S. G. iron although it is only one half as powerful as silicon in this respect. Nickel tends to stabilise pearlite. Up to a certain limit, nickel is useful in giving higher yield and ultimate strength to the S. G. iron, but the build up of the residual nickel content beyond 1 percent from use of returned scrap is disadvantageous as it will appreciably lengthen the annealing cycle necessary to give a fully ferritic structure required for optimum ductility and toughness.

3.8 Other Elements — Some of the elements, such as titanium, telurium, lead, etc, are known to exert some inhibiting influence on spheroidal graphite formation. The harmful influence of these elements could, however, be countered by the addition of small quantities of Misch metal (cerium) subsequent to or along with the normal magnesium additions.

4. PHYSICAL CONDITION OF THE BASE IRON

4.1 There are certain phenomena in the S. G. iron production, such as inverse chill, which can neither be explained nor controlled with chemical composition alone. Some base irons are better suited for spheroidizing treatment and will develop higher or lower nodule counts, more or less ferritic, etc, than others with identical composition. One such condition which influences this phenomena is that of the maximum melt temperature. High superheat temperatures are harmful in causing as cast carbides to form. For this reason, heating the iron above 1 480°C should be avoided whenever possible and if this is unavoidable the molten iron should be held above 1 480°C for as short a period as possible.

5. CHARGE MATERIALS

5.1 Pig Iron — The pig iron available in India in general contains 0·3 to 0·4 percent phosphorus and as the percentage of this element in the base iron is required to be kept as low as possible, the use of pig iron in the charge is best avoided. The Indian pig iron also contains certain tramp elements described in **3.8** above and its use is ruled out on this count also.

5.2 Steel Scrap — Steel scrap should form a major constituent of the charge materials. It should be of a consistent quality and should not contain elements which interfere with the spheroidization of graphite (for example lead) or cause carbides to form (for example chromium). It should be relatively low in manganese content, particularly for ferritic grades. Sheet metal scrap is usually considered as an ideal charge material for production of S. G. iron.

5.3 S. G. Iron Returns — S. G. iron returns should form the remainder of the charges. Where nickel magnesium alloy is used for treatment, care should be taken that nickel percentage in the base iron does not build up beyond 1 percent, particularly for ferritic grades.

5.4 Other Charge Materials — Other charge materials consist of ferro-alloys and carburizing agents. Ferro-alloys should be of known chemical composition, free from deleterious elements, such as chromium and boron.

6. MELTING UNITS

6.1 Cupolas — Since steel scrap forms a major constituent of the charges, acid lined cold blast cupolas are unsuitable as melting units under Indian conditions because of the low carbon pick-up and low tapping temperatures. Acid lined hot blast cupolas are also unsuitable as the high carbon percentage required in the base iron cannot be attained with the high steel scrap charges. Basic lined or liningless hot blast cupolas used in conjunction with basic slag practices are suitable for the production of S. G. iron, since it is possible to reduce the sulphur content to a very low level and obtain sufficiently high carbon in the melt.

6.2 Air Furnaces — Air furnaces either reveberatory or rotary type are unsuitable since the oxidizing flame required to bring the melt to the required temperature results in high carbon loss.

6.3 Induction Melting Furnaces — Coreless induction melting furnaces of main frequency type are ideal for melting base iron under Indian conditions since both the chemical composition and the temperature can be closely controlled. High frequency induction type furnaces can also be used, but because of the size limitations these are not commonly used.

6.4 Electric Arc Furnaces — Direct arc furnaces particularly basic lined ones which are capable of giving a base iron of very low sulphur content can be successfully used for melting base iron, but are not commonly used. Indirect arc and electric resistance furnaces have poor melting economy and are seldom used on a commercial scale for production of base iron.

7. DESULPHURIZATION OF THE MELT

7.1 After having obtained a melt of base iron having suitable composition and temperature as discussed in **5**, the next step in the production of S. G. cast iron is the desulphurization of the melt to reduce the sulphur content to less than 0·03 percent. Although it is possible to treat base irons containing sulphur higher than this limit, the production becomes uneconomic due to the necessity of using larger quantities of costly treatment alloys. This step is not necessary in the case of metal obtained from basic hot blast cupola and basic arc furnace or when a very low sulphur charge is used in acid arc furnace or induction furnace. In all other cases, the sulphur will be usually high and is required to be brought down to the level indicated. Molten iron is desulphurized by bringing it into contact with soda ash, calcium carbide, or quicklime. The efficiency and speed of desulphurization increase with the area of interface contact. Therefore, the use of these agents on the surface of the bath in a forehearth or in the ladle is of the lowest efficiency. Most efficient methods use injection of these agents as powders through graphite lances using inert gas stream as a carrier to agitate the iron under a surface covering. Alternatively, a stream of inert gas is introduced through a porous plug at the bottom of the ladle and desulphurizing agent is thrown on top of the iron. This method is described in detail under **9.2.2.2**. Shaking ladles which are mechanically shaken to induce stirring of the metal are also in use, but the capital cost of the equipment and the temperature loss is very high. All these methods are designed to increase the area of interface contact of the desulphurizing agent. The amount of sulphur removed depends on the type and amount of desulphurizer used, the contact time and the method of creating interface. Proprietory desulphurizing compounds are also available in the market and it is claimed that these are effective as ladle additives. It is, however, necessary to repeat the treatment twice or thrice by transferring the metal to the furnace and repeating the treatment in the ladle. Although the method is not as efficient as injection method, a fairly satisfactory reduction of sulphur can be obtained. Addition of desulphurization agents directly in the induction melting furnace is also practised, but this may to some extent affect the life of furnace lining.

8. TREATMENT ALLOYS

8.1 Magnesium Master Alloys — Either pure magnesium or alloys containing magnesium are used for introducing magnesium into the iron, the selection of a specific alloy depending primarily on other process variables and the desired end product. Most foundries use a master alloy containing magnesium. The more commonly used treatment alloys are the master alloys of either silicon or nickel with magnesium. A small quantity of cerium is added in some of the alloys. A large number of magnesium master alloys are available in the market. A list of the most commonly used magnesium master alloys for treatment is given in Table 1. In addition to these master alloys, magnesium impregnated coke, containing about 40-45 percent magnesium and magnesium-iron briquets containing 15-20 percent magnesium can also be used with economic advantage if readily available.

TABLE 1 CHEMICAL COMPOSITION OF COMMONLY USED MAGNESIUM MASTER ALLOYS

(*Clause* 8.1)

Sl No.	Alloy	Constituents, Percent Max						
		Magnesium	Silicon	Nickel	Iron	Calcium	Aluminium	Cerium
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	*Nickel Base*							
	Nickel Magnesium	15	—	85	—	—	—	—
	Nickel Silicon Magnesium	15	30	50	—	—	—	—
ii)	*Silicon Base*							
	Ferro-Silicon Magnesium	5	45	—	Remainder	1	1	—
	Ferro-Silicon-Magnesium-Cerium	5	45	—	do	1	1	0·5
	Ferro-Silicon-Magnesium	9	45	—	do	1	1	—
	Ferro-Silicon-Magnesium-Cerium	9	45	—	do	1	1	0·5
	do	15	45	—	do	1	1	0·5
	do	15	45	—	do	1	1	—
	do	20	50	—	do	1	1	0·5
	do	20	50	—	do	1	1	—
	do	30	50	—	do	1	1	0·5
	do	30	50	—	do	1	1	0·5

8.2 Choice of Master Alloys — Use of master alloys provides a simultaneous addition of one or more alloying elements, usually nickel and/or silicon. Meeting certain specifications may require intentional alloying with or limiting the addition of either of these elements, thus limiting the choice of magnesium alloy. Of the carrier elements in magnesium alloys, only silicon is always required in S. G. cast iron treatment. Silicon promotes spheroid regularity, ferrite in the matrix, better elongation and improved annealing response and control of carbide occurrence. In the fully annealed ferritic grade, very high silicon content hardens the matrix and raises the critical transition temperature under conditions of shock loading. For this reason silicon content should be restricted to 2·5 to 2·75 percent in grades, such as S. G. 370/17 of IS : 1865 - 1974[*]. Nickel as an alloying element in S. G. cast iron promotes pearlite stability and higher tensile strength in all sections and increased response to hardening and strengthening heat treatments, such as required for grades S. G. 800/2 and S. G. 700/2. Where the alloying effect of nickel is desirable, the nickel base alloys are generally used and provide lower treatment cost than would the use of silicon base alloy plus separate nickel additions. Where nickel is not required, lower treatment costs are provided by the silicon base alloys. In other words, silicon base alloy would be preferable for ductile grades and nickel base for high strength grades. In India, availability and cost of master alloys is an important factor. A nickel magnesium alloy containing 85 percent and 15 percent magnesium is now available indigenously but is very expensive. Currently, ferro-silicon magnesium alloys containing from 5 to 30 percent magnesium are also available from indigenous sources. The present production of S. G. iron in the country is based on these two types of alloys. Use of pure magnesium, because of the difficulties of introducing it in the melt is uncommon in India.

8.3 Calculations

8.3.1 Amount of magnesium bearing alloy is calculated on the basis of base sulphur of molten iron and efficiency of the treatment process. The efficiency of the process is effected by the technique used and temperature of molten iron.

Amount of magnesium bearing alloy can be calculated from the following relationship:

$$W \text{ percent} = \frac{10\,000\,(Mg_r + 0{\cdot}75\,S)}{Mg_a \times E}$$

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[*] Specification for iron casting with spheroidal or nodular graphite (*second revision*).

where

W percent = addition as percentage by weight of molten metal,

Mg_a = magnesium content of alloy in percent,

Mg_f = desired ' residual ' magnesium percent,

S = percent sulphur in iron to be treated, and

E = efficiency of addition or magnesium recovery.

8.3.1 With same type of alloy, the Mg recovery varies between 25 percent to 75 percent depending on the temperature and method of treatment. As a rule Ni-base alloys give better recoveries, but for economic reasons, their use is restricted to high strength grades.

8.3.2 The recovery is greatly affected by metal temperature and varies inversely with the temperature. There is a drop in temperature during the treatment for desulphurization, spheroidization and inoculation, and hence the initial temperature of the metal should be so adjusted that the temperature of the metal to be poured in the moulds falls within the ranges shown in Table 2.

TABLE 2 POURING TEMPERATURES FOR CASTINGS

SECTION THICKNESS mm	TEMPERATURE °C
4 up to 13	1 425-1 455
Above 13 up to 28	1 400-1 435
Above 28 up to 100	1 370-1 415

9. SPHEROIDIZATION TECHNIQUES

9.1 Classification of Processes — The large number of processes and techniques in use for graphite spheroidization can be broadly classified into the following two categories:

a) Processes which use Mg master alloys, and

b) Processes which use pure magnesium.

The first category can be further subdivided as follows:

a) Ladle transfer processes, and

b) Processes other than ladle transfer.

9.1.1 The processes in commercial use which come under these categories are as follows:

a) *Processes Which Use Mg Master Alloys*

  1) *Ladle transfer processes*

    Open ladle process
    Sandwich process
    Puddling process
    Trigger process

  2) *Processes other than ladle transfer*

    Plunging process
    Porous plug practice
    In-mould process
    T-knock process
    Flow through or Flotret process

b) *Processes Which Use Pure Magnesium*

    Pressure ladle technique
    Injection process
    G. F. convertor process
    Detachable bottom ladle process

9.1.2 The ladle transfer techniques are simple to use and very popular and hence a large majority of S. G. irons today are produced by this method. Next in popularity are plunging technique and porous plug process. Among the remaining processes, in-mould process and G. F. convertor process are likely to be popular, particularly for large volume production.

9.2 Processes Which Use Mg Master Alloys

9.2.1 *Ladle Transfer Processes* — In ladle transfer processes, the master alloy is either placed at the bottom of the treatment ladle and liquid iron poured over it or the alloy is added while the metal is being transferred to the treatment ladle. The treatment ladles should be tall, that is the height should be twice the dia at the top, in order to prevent splashing of the metal. Size of the master alloy is important. A uniformly small size of 20 mm to 10 mm is ideal. Large sizes react too slowly and may cause excessive turbulance while fines react too fast and burn off before sufficient metal is in the ladle.

9.2.1.1 *Open ladle process* — In this process the magnesium master alloy is added into the metal stream as the metal is either tapped from the furnace or transferred from pouring ladle into the treatment ladle. Recoveries are lower and of the order of about 25 percent.

9.2.1.2 *Sandwich process* — In this method pieces of magnesium alloy are placed in a recess at the bottom of the treatment ladle, and are covered by thin steel punchings as shown in Fig. 1. Iron to be treated is poured into the ladle directing the stream away from the sandwich, so that the onset of the magnesium reaction is delayed until the ladle is partially full. The steel punchings should be 1·5 to 3 mm thick and should form 1 to 1·5 percent by mass of the iron to be treated. The recoveries depend on temperature and can be as high as 50 percent with proper practice. The drop in temperature is one of the disadvantages.

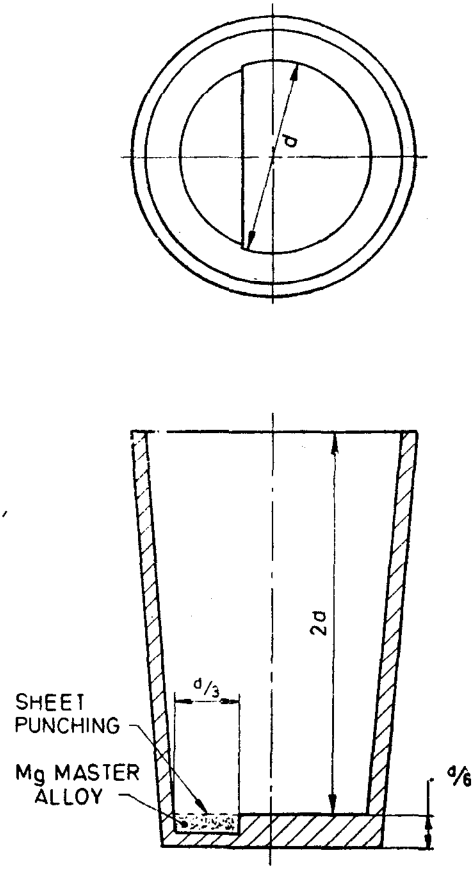

FIG. 1 SANDWICH PROCESS

9.2.1.3 *Pudding process* — For a smooth operation by this method, two melting units are required one small unit holds the liquid iron at a very low temperature between 1 200°C to 1 230°C, and a small quantity of this cold iron is overtreated with magnesium alloy utilizing the excellent recovery at this low temperature (about 80 percent). The over treated iron is then diluted with iron held at about 40 to 60°C above the desired pouring temperature. The rate of dilution may be as high as 5 percent overtreated cold iron and 95 percent hot iron. Overall magnesium recovery is about 30 percent.

9.2.1.4 *Trigger process* — This process is similar to sandwich process, with the difference that the steel punchings of the sandwich are replaced by a thin layer of resin bonded sand. The resin bonded sand gets cured and creates a shell which prevents the onset of the reaction until after the ladle is full. The reaction is then triggered by breaking the shell with a heated rod. Unlike sandwich process, the temperature drop is much less and the recoveries somewhat higher than with sandwich process and up to 60 percent.

9.2.2 *Processes Other Than Ladle Transfer*

9.2.2.1 *Plunging process* — In this method, the Mg alloy is contained in a can and set into a refractory or graphite plunger bell. The treatment ladle is similar to that shown in Fig. 1, that is tall but has no recess at the bottom. The ladle is filled to 2/3rd its height with iron to be treated and a plunger with a protective cover attached is lowered mechanically to well below the liquid iron surface so that 50 to 75 mm clearance is left between the bottom of plunger and ladle as shown in Fig. 2. Mg recoveries are up to 60 percent. The disadvantages of the process are that the plunging equipment requires maintenance and the refractory bell adds to the cost of the treatment. Treatment time is longer and temperature loss higher.

9.2.2.2 *Porous plug practice* — In this method, bottom of the ladle is fitted with a refractory plug which is permeable for gases but not for liquid iron. A hose connects the porous plug to a pressurized inert gas (usually nitrogen) supply, so that gas under 0·35-0·70 MPa pressure can enter the liquid iron and the bubbles which form create a vigorous agitation of the entire melt, as shown in Fig. 3. Pressure is determined by the required gas volume which is 0·14 to 0·28 m^3/min. The treatment alloy is simply thrown on top of the liquid to be carried below the surface within moments. Mg recoveries are between 30 to 50 percent. Temperature loss is excessive if less than 500 kg of iron is treated. To compensate for this drawback, large ladles can first be desulphurized by the same method using calcium carbonate, slag removed and then treated with magnesium alloy.

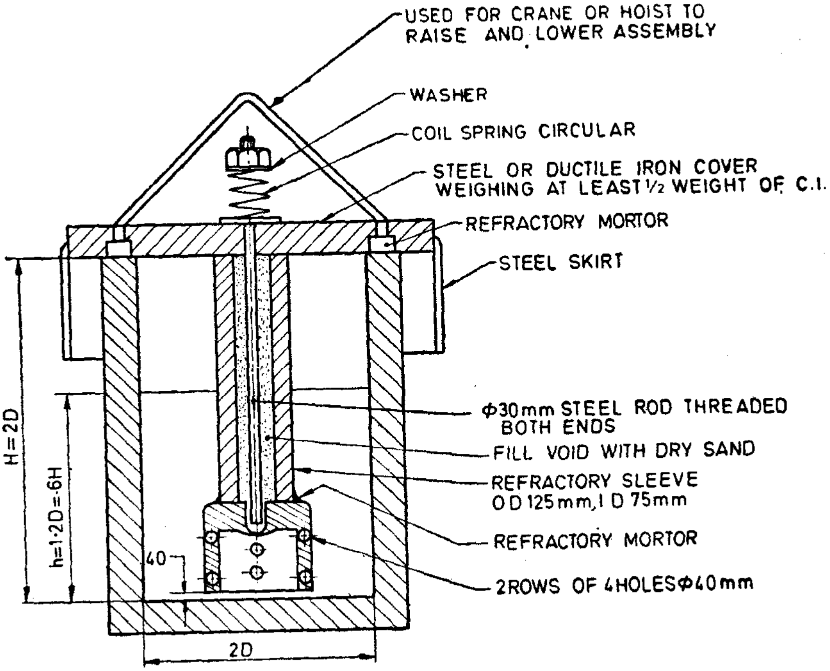
USED FOR CRANE OR HOIST TO RAISE AND LOWER ASSEMBLY
WASHER
COIL SPRING CIRCULAR
STEEL OR DUCTILE IRON COVER WEIGHING AT LEAST 1/2 WEIGHT OF C.I.
REFRACTORY MORTOR
STEEL SKIRT
Φ30mm STEEL ROD THREADED BOTH ENDS
FILL VOID WITH DRY SAND
REFRACTORY SLEEVE OD 125mm, ID 75mm
REFRACTORY MORTOR
2ROWS OF 4HOLESΦ40mm
H=2D
h=1·2D=·6H
40
2D

FIG. 2 PLUNGING PRACTICE

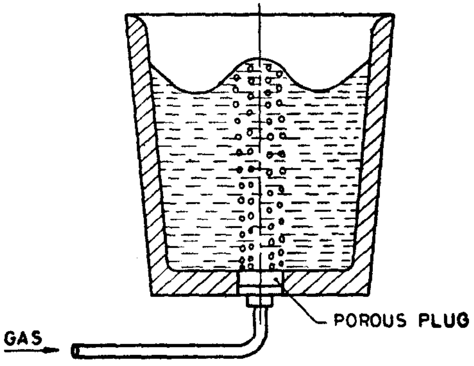

FIG. 3 POROUS PLUG PRACTICE

9.2.2.3 *In-mould process* — In this process the iron is treated within the mould itself. The reaction chamber, which holds the treatment alloy and inoculants, is moulded into the gating system as shown in Fig. 4. The process needs iron, which is desulphurized to below 0·02 percent. Because of the extensive gating system the casting yield is low. The magnesium recoveries are 35 to 65 percent. The process is particularly suited to completely automated pouring systems.

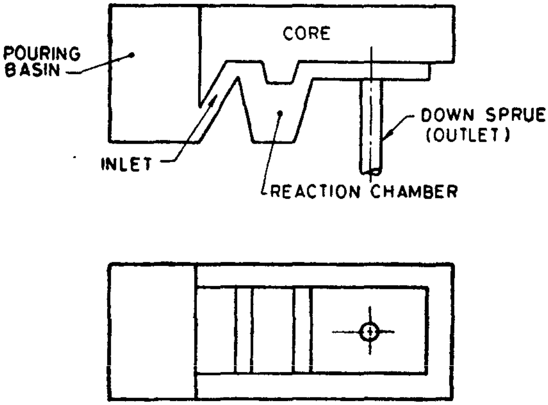

FIG. 4 IN-MOULD PROCESS

9.2.2.4 *T-knock process* — This process uses an elongated launder located with its exit opening above the receiving ladle. The iron to be treated is poured into a basin at the other end of the launder and flows into the treatment basin with the exit opening at its bottom. A refractory tube which is inserted into this basin can be fed with magnesium master alloy at a predetermined rate. The arrangement is shown in Fig. 5. Launder filling and master alloy feeding begins nearly simultaneously and the existing master alloy is entirely surrounded by the stream of the metal. The treatment is finished when about 50 to 75 percent of the iron has gone through and is followed immediately with inoculation using the same equipment with remaining metal. Magnesium recoveries at 1 480°C are claimed to be in the vicinity of 75 percent.

9.2.2.5 *Flotret process* — In this process the treatment is somewhat similar to the T-knock process excepting that the launder is replaced by a closed channel with a pouring basin at one end and a vertical exit hole at the other end. In between is the reaction chamber containing the master alloy. The arrangement is shown in Fig. 6. The chamber is cleaned and master alloy replaced after each treatment. No performance data adequate for reliable evaluation is available as yet.

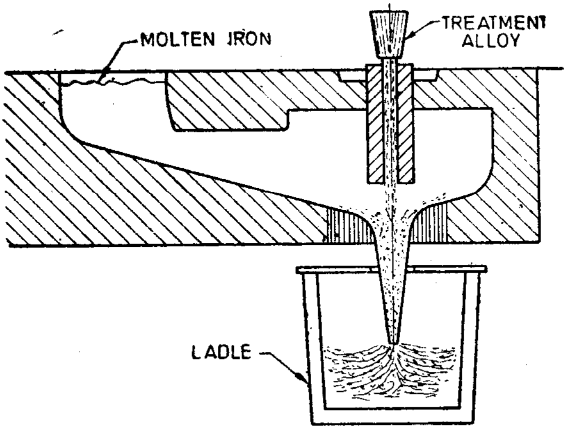

FIG. 5 T-KNOCK PROCESS

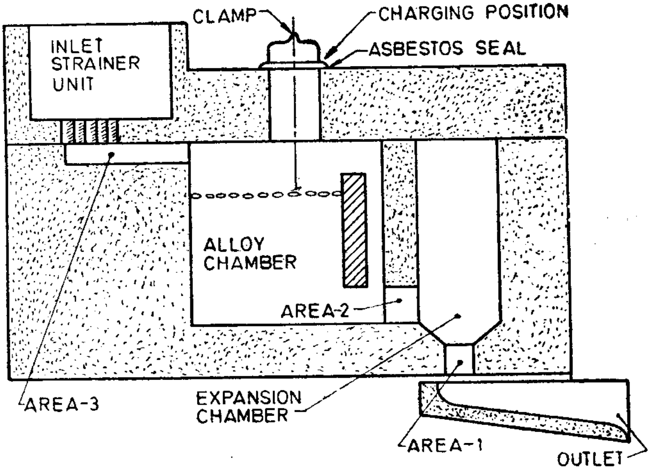

FIG. 6 FLOTRET PROCESS

9.3 Processes Which Use Pure Magnesium

9.3.1 *Pressure Ladle and Pressure Chamber Techniques* — Metallic magnesium melts but does not boil at practical treatment temperatures as long as it is held under 15-30 times atmospheric pressure. If the ladle is completely sealed and the internal pressure raised to 2·8 MPa (pressure ladle), magnesium can be introduced into liquid iron with no reaction other than burning if air pressure is used and without burning if a protective gas is pressurised in the space above the liquid iron. The same result is obtained if an ordinary ladle is placed into a pressure tight chamber (pressure chamber technique) and the same high pressure is created inside the chamber. This is the principle of pressure ladle and pressure chamber techniques. The arrangements are shown in Fig. 7 and 8 respectively. Pure magnesium is used in both the techniques and magnesium recoveries up to 80 percent can be obtained. The treatment is very economical but the equipment is expensive in initial cost and maintenance.

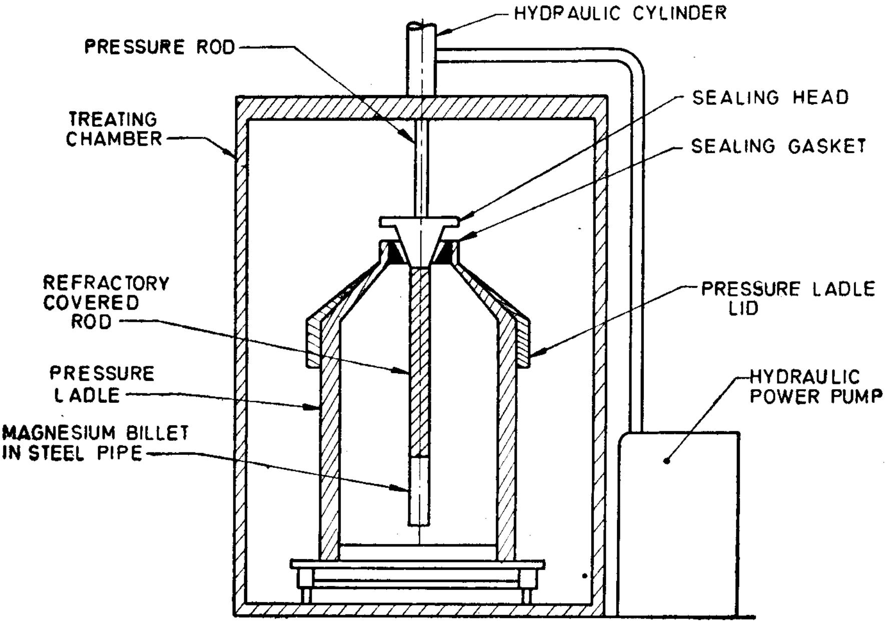

Fig. 7 Sealed Ladle Technique

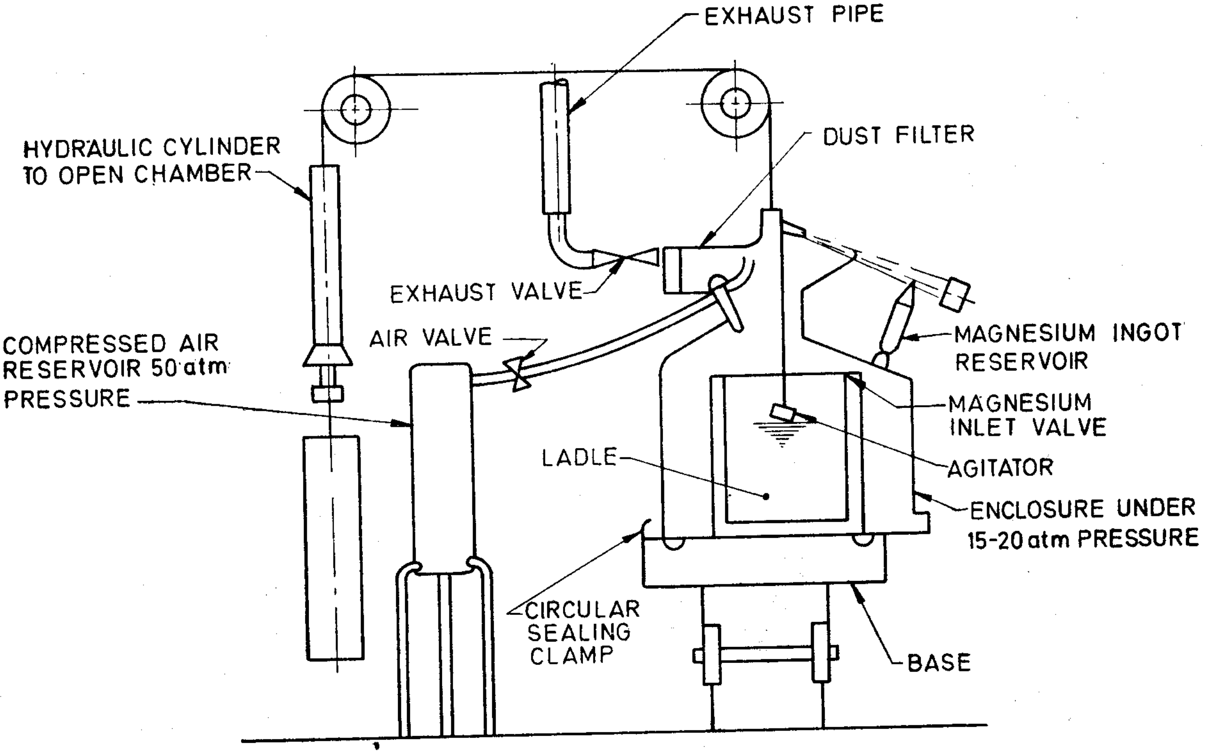
EXHAUST PIPE
HYDRAULIC CYLINDER TO OPEN CHAMBER
DUST FILTER
EXHAUST VALVE
AIR VALVE
COMPRESSED AIR RESERVOIR 50 atm PRESSURE
MAGNESIUM INGOT RESERVOIR
MAGNESIUM INLET VALVE
LADLE
AGITATOR
ENCLOSURE UNDER 15-20 atm PRESSURE
CIRCULAR SEALING CLAMP
BASE

FIG. 8 PRESSURE CHAMBER TECHNIQUE

9.3.2 *Injection Process* — This method is similar to the injection of calcium carbide for desulphurization described earlier. The only difference is that magnesium is injected instead of calcium carbide. In this process, fine particles of magnesium are carried in a stream of inert gas (usually nitrogen), through a graphite tube immersed in the liquid metal as shown in Fig. 9. The tube is fixed to a cover and the injection continues until all magnesium is in iron, when the cover is raised and nitrogen turned off. Recoveries of magnesium are 40 to 70 percent.

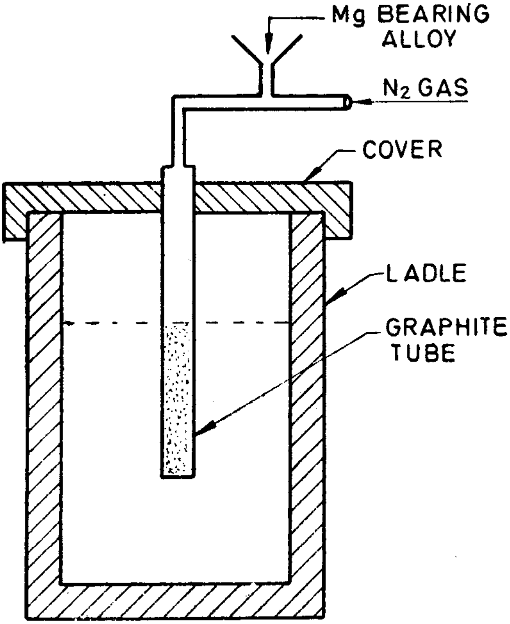

FIG. 9 INJECTION PROCESS

9.3.3 *G.F. Convertor Process* — Reaction chamber is an important element of convertor, which holds the magnesium and controls its evaporation. Chamber size depends upon the amount of pure magnesium needed for the amount of iron and sulphur content of the metal. Carburization and alloy additions can also be done in the convertor including additions having lower boiling point or lower density than molten iron. The magnesium is placed in the reaction chamber and metal is poured in the convertor. The convertor is now rotated through 90° to bring contact between molten iron and magnesium. After treatment the convertor is tilted to pour out the metal. The three stages of convertor are shown in Fig. 10. Recovery averages 80 percent.

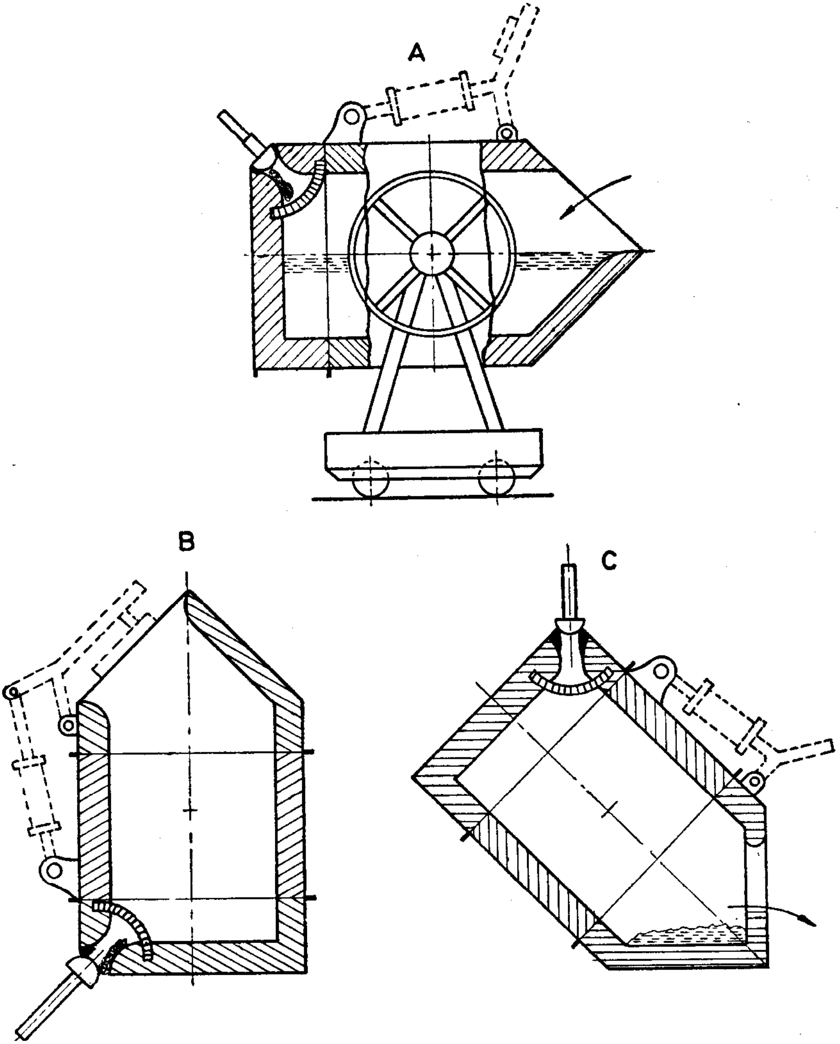

FIG. 10 CONVERTOR FOR TREATMENT WITH METALLIC MAGNESIUM

9.3.4 *Detachable Bottom Ladle Process* — In this practice, the ladle is a conventional refractory lined shell open at both ends, with a separate detachable bottom and a semi permanent refractory honeycomb structure located across the interior of ladle slightly above the bottom end. Magnesium coke lumps or other treating agents are kept between lower end of honeycomb structure and the detachable bottom as shown in Fig. 11. The detachable bottom provides a means of removal of the spent coke after iron treatment. A leak proof seal is formed between the detachable bottom and the ladle lining through the use lightly rammed moulding sand. The magnesium recovery is between 40-50 percent at the normal treatment temperatures.

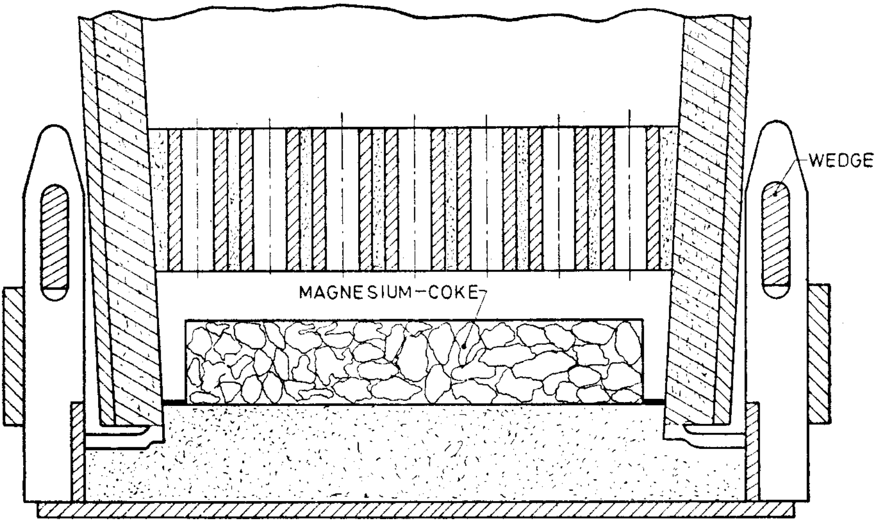

FIG. 11 ASSEMBLY VIEW OF LOWER PORTION OF DETACHABLE BOTTOM TREATING LADLE

10. INOCULATION OF SPHEROIDIZED MELT

10.1 When magnesium is added to relatively soft base grey iron, it changes the shape of flake graphite, making it nodular or spheroidal. Magnesium also strongly promotes the formation of cementite. If spheroidal graphite iron is to have good ductility, a late silicon addition or inoculation must be made to the melt after magnesium is added. The inoculation treatment results in higher nodule count and suppresses the formation of carbides. The silicon content of the base iron is kept low enough so that the silicon from the magnesium alloy (when silicon-magnesium alloy is used) and the inoculation adjusts final silicon content to the desired range. Alloys used for inoculation include ferrosilicon containing either 75 or 85 percent silicon or a calcium bearing ferrosilicon with 85 percent silicon in the conventional process. Effective inoculation can be made by (a) reladling the metal after the magnesium addition, and adding the inoculant as the metal is poured or (b) adding the magnesium to the first half of the tap or pour and then adding the inoculant to the last half. Immediately after inoculation the metal is ready for pouring into the moulds. Pouring of moulds should be completed within 10 minutes after the treatment, since the effect of treatment fades after this interval and the metal solidifies as grey iron instead of spheroidal graphite iron.

11. CONTROL TESTS

11.1 Acceptance criteria for the castings are based on mechanical properties as determined on the *U* or *Y* type of keel test bars specified in IS : 1865-1974* which also specifies frequency of tests to be carried out for this purpose. However, since the tensile test results can be made available only after a day or two, it is necessary to have some control test to determine the quality of the iron produced. Since it is the micro-structure which determine the mechanical properties of the S. G. iron, best control can be achieved by examining micro-structure of a specimen from each ladle. Although it is possible to co-relate the mechanical properties with the micro-structure, this involves, establishment of suitable standards by each foundry. For all practical purposes, it would be sufficient to ensure that the micro-structure satisfies the requirements specified. After the ferro-silicon inoculation is completed a sample as shown in Fig. 12 is poured into a test coupon core which has a heavy centre and two lugs of dimensions 19 × 19 × 6 mm on either side of this centre. The sample is allowed to cool sufficiently for handling and then is quenched in water. The test lug is broken from the test coupon as soon as possible. The fractured surface of the lug is immediately rough ground to a flat plane and rapid polish through four emery papers gives a somewhat scratchy, but readable microscopic sample. The mechanical properties are influenced both by matrix and shape and size of graphite. Since the sample cools at a different rate from the castings, evaluation of the matrix structure of the sample is of no consequence. Graphite structure can however be satisfactorily evaluated and timely action taken to eliminate unsatisfactorily treated irons finding their way into the castings. The sample should be taken from the last iron to be poured. This test can be completed within 15 minutes and is useful in detecting castings poured from unsatisfactorily treated iron before they are knocked out and get mixed with other castings. It would only be necessary to mark the moulds represented by each test coupon.

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*Specification for iron castings with spheroidal or nodular graphite (*second revision*).

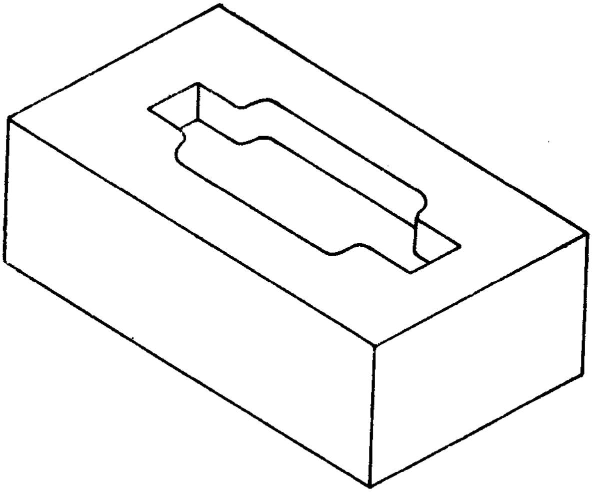

FIG. 12A TEST COUPON CORE

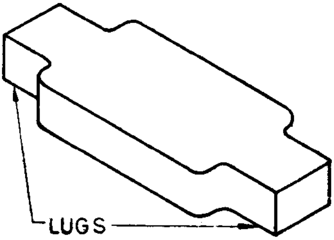

FIG. 12B TEST COUPON

12. MOULDING AND GATING PRACTICE

12.1 Moulding practice is similar to that of grey iron, excepting that allowance has to be made for slightly different shrinkage characteristics and some modifications to the gating system due to the dross forming tendency of S. G. iron.

12.2 Pattern Shrinkage — With substantially pearlitic matrix, which is common with the S. G. iron castings, the pattern shrinkage is 13 mm/m. On annealing to completely ferritic structure, as required for grades S. G. 400/12 and S. G. 370/17, it grows about 4 mm/m.

12.3 Gating Practice — Because of the dross forming tendency of the metal, the gating system should be designed to fulfil the following conditions:

a) Retain the slag and dirt in the gating system ahead of the mould cavity,

b) Introduce the metal into the mould with as little turbulance as possible, and

c) Control the rate of entry of metal into the mould cavity.

12.3.1 There are gating systems which are designed to produce clean castings:

a) Positive pressure system in which the choke occurs at the junction of the runner bar and ingate. This results in reduction of metal velocity in the runner system to allow slag or in inclusion to rise and be trapped in the runner. A gating ratio of 4 : 8 : 3 has been found to be satisfactory in service.

b) Tranquil flow or reverse choke system in which the choke occurs immediately after the sprue. This is particularly designed for plate type of castings.

In order to reduce turbulence of the metal, it is desirable to position the gates at the bottom of the casting and the ingates must be taken from the bottom of runner section.

13. HEAT TREATMENT

13.1 When properties are desired which are difficult to obtain ' as cast ' S. G. iron may be heat treated. Heat treatments given to S. G. iron include stress relief, sub-critical annealing, full annealing, normalizing, quenching and tempering and surface hardening. Temperatures and times may vary somewhat from the indicated typical norms, depending upon composition the metal and size of castings. Typical heat treatment processes are as follows.

13.1.1 *Stress Relief*

a) Heat to 590°C and hold at the temperature for 2 hours plus one hour per 25 mm of section thickness.

b) Furnace cool at a rate of 55°C per hour to 340°C, and

c) Remove from furnace and cool in air.

13.1.2 *Sub-Critical Annealing*

a) Heat to 700°C and hold for 5 hours plus one hour per 25 mm of section thickness,

b) Cool at a rate of 110°C per hour to 480°C, and

c) Remove from furnace and cool in air.

13.1.3 *Full Annealing*

a) Heat to 900°C and hold for 2 hours plus one hour per 25 mm of section thickness,

b) Cool to 700°C and hold for 5 hours (if the cooling is fast, add 1 hour per 25 mm of section thickness),

c) Cool at a rate of 110°C per hour to 480°C, and

d) Remove from furnace and cool in air.

13.1.4 *Normalizing* — Normalizing is commonly followed by stress-relief (tempering) to reduce hardness and relieve residual stresses that develop when various parts of a casting are cooled in air at different rates:

a) Heat to 900°C and hold for 1 hour plus one hour per 25 mm of section thickness, and

b) Remove from furnace and air cool (castings 25 mm and thicker may need cooling by air blast).

13.1.5 *Quenching and Tempering*

a) Heat between 870°C to 900°C and hold for 1 hour plus one hour per 25 mm section thickness,

b) Quench in oil, and

c) Temper at 430°C to 650°C depending on the desired hardness and strength. Holding time at tempering temperature is 2 hours plus 1 hour per 25 mm of section thickness followed by air cooling.

13.2 Applications

13.2.1 *One or More Heat* — Treatment process may be selected in the production of castings, depending upon the intended purpose/application.

Guidelines for selection are as follows:

Sl No.	*Heat Treatment*	*Application*
1.	Stress Relief	To reduce or eliminate high residual stresses causing distortion or cracking during subsequent machining or heat treatment. Stress relief would reduce distortion in cases where significant portion of the castings is removed by machining. Stress relief is also advisable prior to and after induction hardening and may be necessary after normalising.
2.	Sub-Critical Annealing	Alternate to annealing, when cast carbides are not present in the castings. Not recommended in case of as cost structures when maximum impact properties are required.
3.	Full-Annealing	Maximum ductility and best machinability (for ferritic grades).
4.	Normalizing	For high strength (pearlitic structures) (U. T. S. 70 to 100 kg/mm^2). Commonly tempered after normalising.
5.	Quench and Tempering	For higher hardness and strength. (U. T. S. 100 to 120 kg/mm^2).

14. CASTING DEFECTS

14.1 Apart from the normal casting defects associated with foundry methods and moulding materials, there are a few defects characteristic of S. G. iron. Their causes and guidelines to avoid them are given below:

Sl No.	*Defect*	*Causes*	*Remedial Action*
1.	Graphite nodule floatation or segregation	Incorrect C. E. for the casting section	Keep carbon equivalent below 4·3

Sl No.	*Defect*	*Causes*	*Remedial Action*
2.	Massive carbides	i) Rapid cooling of thin sections	Locate flow offs or bobs at critically thin sections
		ii) High residual magnesium content	Keep residual Mg content between 0·03 to 0·05 percent
		iii) Low final silicon content	Keep silicon content above 2·5 percent
		iv) High superheat temperature of the base-iron	Do not superheat metal to higher than 1 480°C
		v) Chromium and vanadium in the metal	Keep chromium and vanadium less than 0·05 percent in the metal
3.	Inverse chill	Carbides form in the centre of the heavy sections due to the same causes as in (2) above and also ineffective inoculation and loss of inoculating effect due to holding of metal	The remedies are same as given in (2) above. In addition a minimum of 0·6 percent Si should be added in inoculation treatment
4.	Sub-surface inclusions	High melting point non-metallic compounds formed after addition of Mg alloy are trapped near the mould surface when the metal solidifies	A small amount of flourspar or cryolite along with the Mg alloy addition will flux the non-metallic compounds and form a slag that frees itself from the metal

Sl No.	*Defect*	*Causes*	*Remedial Action*
5.	Slag inclusions	Slag formed during desulphurization and magnesium treatment gets trapped in the metal due to incorrect gating practice	Slag formed during treatment should be skimmed off and the gating system should be so designed as to free the slag from metal stream and get trapped in the runner bar (*see* **12.3** for proper gating practice)
6.	Fading	Fading, a term applied to deterioration of spheroidally shaped graphite to flake graphite results from lowering of magnesium content in the treated iron due to long holding time	To avoid this defect, time between magnesium treatment and pouring should be carefully controlled. Sulphur bearing slags should be removed immediately from the metal and tramp elements should be controlled by selection of proper melting charges

INTERNATIONAL SYSTEM OF UNITS (SI UNITS)

Base Units

QUANTITY	UNIT	SYMBOL
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Supplementary Units

QUANTITY	UNIT	SYMBOL
Plane angle	radian	rad
Solid angle	steradian	sr

Derived Units

QUANTITY	UNIT	SYMBOL	DEFINITION
Force	newton	N	1 N = 1 kg.m/s^{2}
Energy	joule	J	1 J = 1 N.m
Power	watt	W	1 W = 1 J/s
Flux	weber	Wb	1 Wb = 1 V.s
Flux density	tesla	T	1 T = 1 Wb/m^{2}
Frequency	hertz	H	1 H = 1 c/s (s^{-1})
Electric conductance	siemens	S	1 S = 1 A/V
Electromotive force	volt	V	1 V = 1 W/A
Pressure, stress	pascal	Pa	1 Pa = 1 N/m^{2}

AMENDMENT NO. 1 OCTOBER 1985
TO
IS: 9630-1980 RECOMMENDED PRACTICES FOR PRODUCTION OF SPHEROIDAL GRAPHITE IRON

[*Page 9, Table 1, Sl No.* (i), *col 6*] - Incorporate the iron content as 5 percent, *Max* against Nickel Silicon Magnesium alloy.

P.K. Gulati

(SMDC 17)

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